

DIAMOND STRIPPING FOILS FOR THE SNS

R. W. Shaw and C. S. Feigerle
Chemical Sciences Division/ORNL
Dept. of Chemistry/Univ. of Tennessee

SNS Seminar
March 28, 2005
Oak Ridge, TN

Overview

- SNS stripping foil application and requirements
- Preliminary BNL foil test data
- CVD diamond foils
 - Microcrystalline diamond
 - Nanocrystalline diamond
- Corrugated diamond foils
- Beam irradiation tests at BNL
- Summary and future directions

Stripping Foil Requirements



- Lateral dimensions: 10-12 x 20 mm
- Thickness: 1 μm (350 $\mu\text{g}/\text{cm}^2$)
- Mechanical support: No more than 2 edges
- Time to failure: 100-200 hours at 2300 K
(GeV beam at 38 mA
during 1 ms pulse)

Preliminary BNL test results indicated that diamond is a good candidate foil material

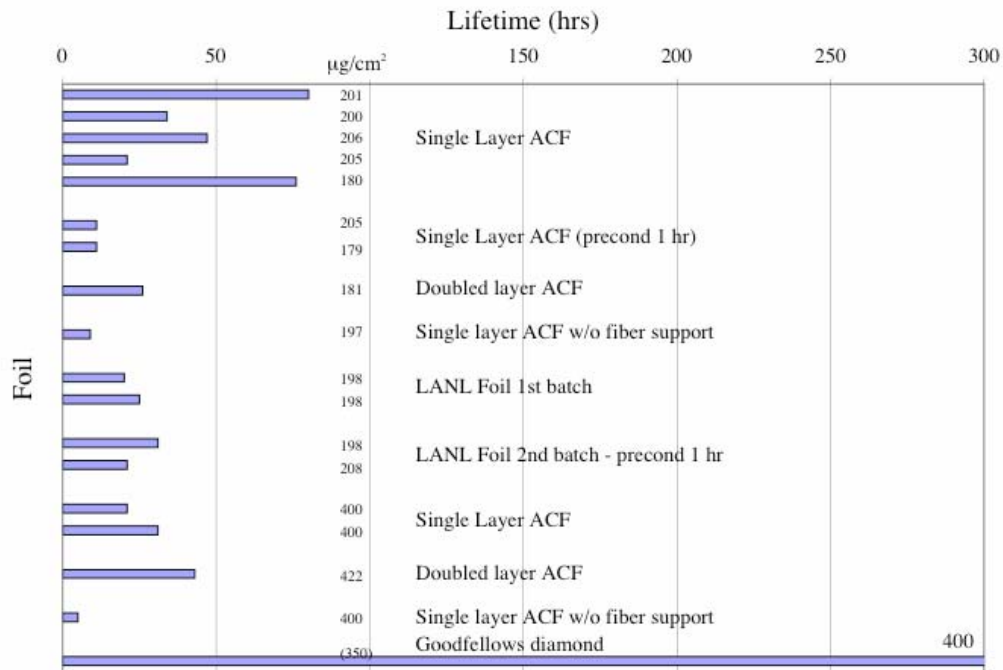
Initial BNL Diamond Foil Experiments



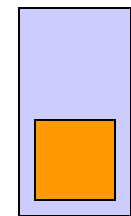
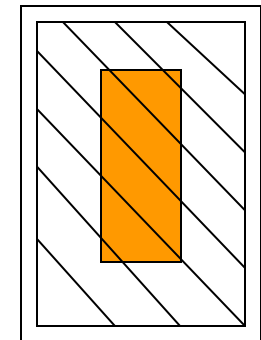
- Traditional carbon foils fail within about 20-50 hours in a simulation beam (750 keV H^- , 6.7 Hz, 2 mA during the 0.5 ms pulse).
- A commercial diamond foil survived up to 400 hours (Liaw, Lee, Tuozzolo).
- However, unsupported diamond foils are unsuitable due to **CURLING** before beam exposure.

Diamond Stripping Foils for the SNS

BNL Carbon Stripping Foil Test Results



Fiber
Supported



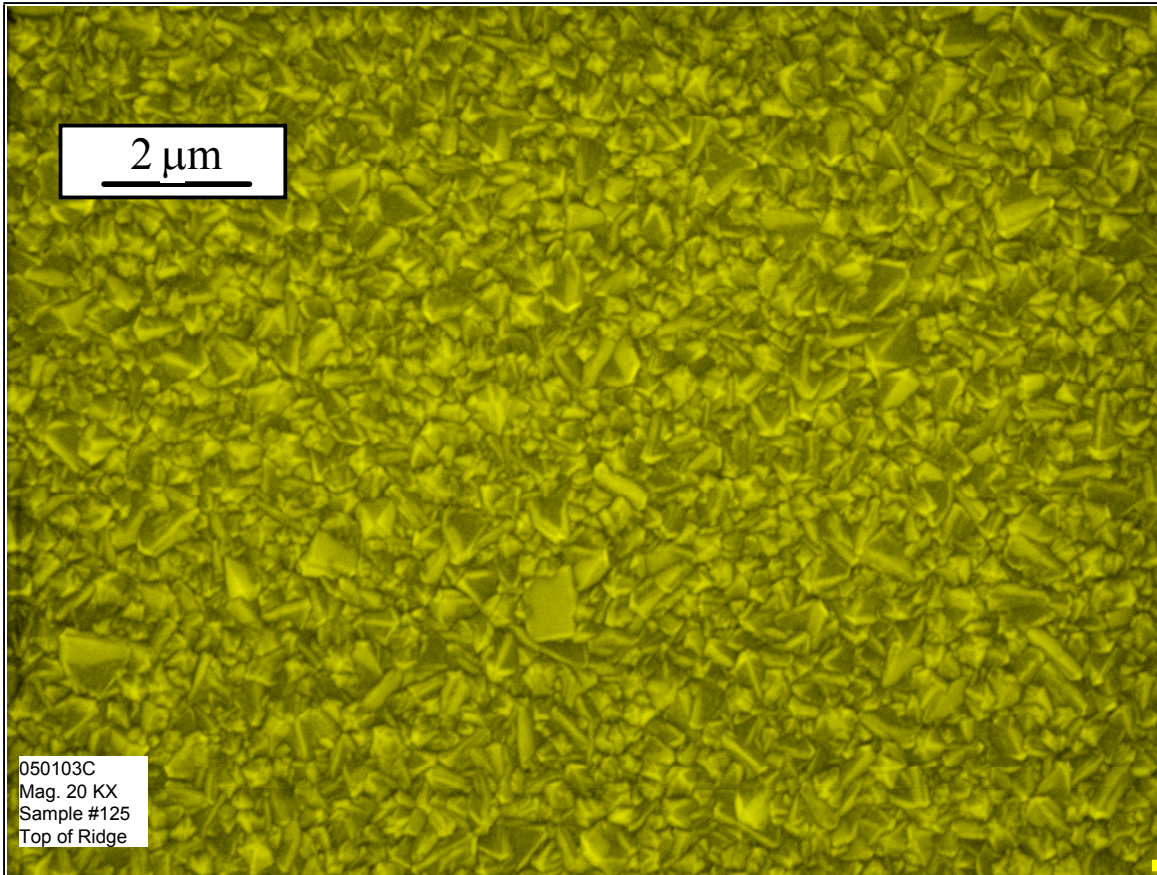
Window
Frame

Liaw, Lee, and Tuozzolo, PAC 2001, Chicago

CVD Diamond Films

- Conventional chemical vapor deposition (CVD) diamond recipe:
 - 0.5 to 2% CH₄ in H₂ at 50-100 Torr
 - 2.45 GHz microwave plasma (or hot filament, flame)
 - Roughened silicon substrate at 800-900 °C
- Currently conducting microwave plasma growth
 - Larger film area
 - Improved thickness uniformity
 - Improved purity (no filament metal)
- Polycrystalline diamond film produced at about 1 μm/hr rate with a grain size up to 1-10 μm
- Vapor phase diamond growth is via a nucleation/enlargement mechanism
- A sufficiently high nucleation density must be achieved to produce a continuous film at 1 μm thickness

Diamond film grown in microwave-powered reactor



1300 W

50 T

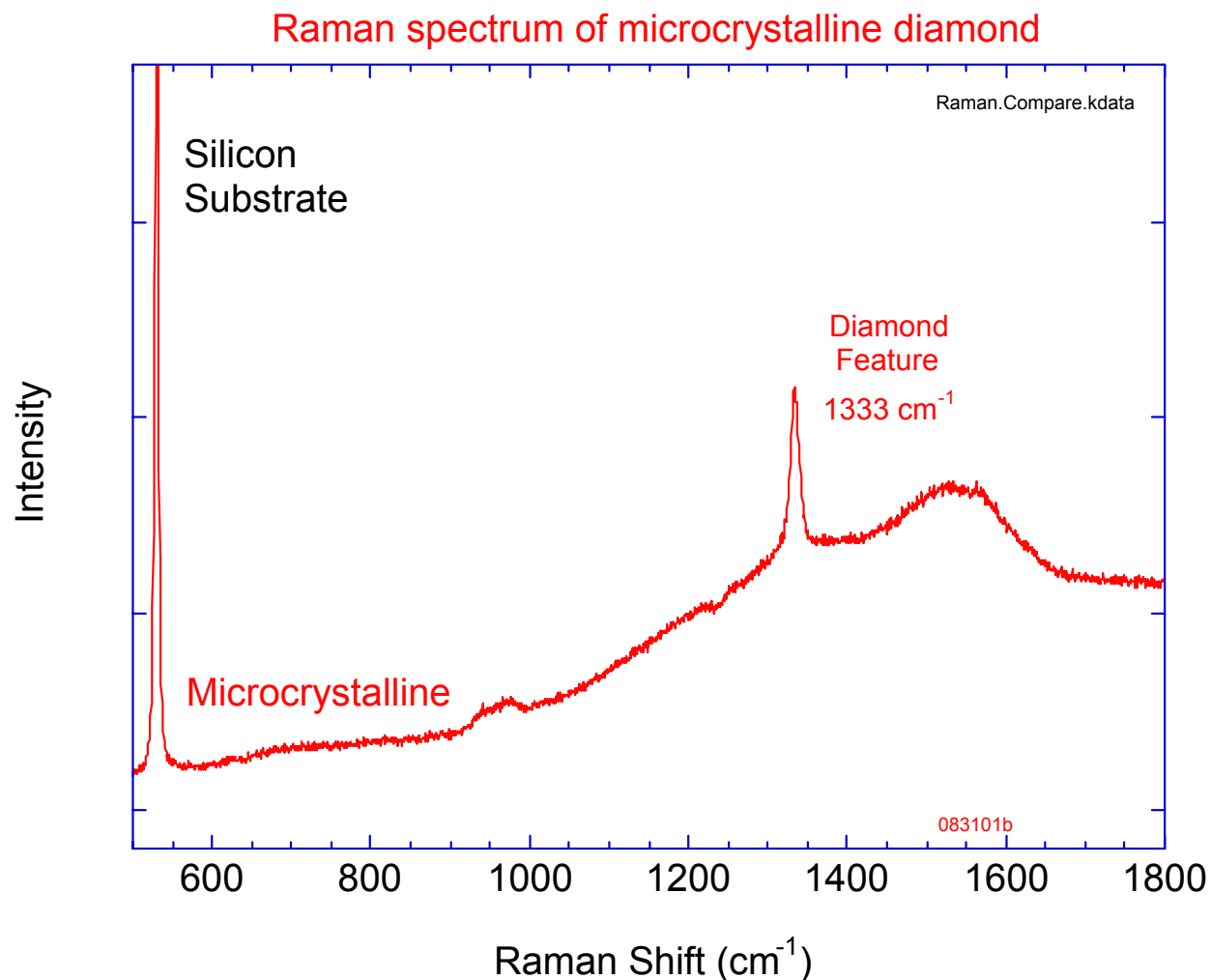
885 T_s

0.99 μm

Corrugated
Foil

BNL Test:
> 120 Hr

Diamond Stripping Foils for the SNS



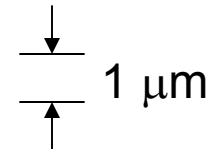
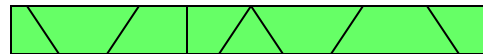
Nanocrystalline CVD Diamond Films

- Nanocrystalline diamond
 - Characteristic grain size is 5 to 50 nm
 - Grown in hot filament or microwave chambers
 - Recipe calls for dilution of the reactant gases with a considerable argon fraction (>90%)
- Can nanocrystalline character strengthen foils ???

Nanocrystalline:



Microcrystalline:



Raman spectra of nanocrystalline CVD diamond

2694 Appl. Phys. Lett., Vol. 77, No. 17, 23 October 2000

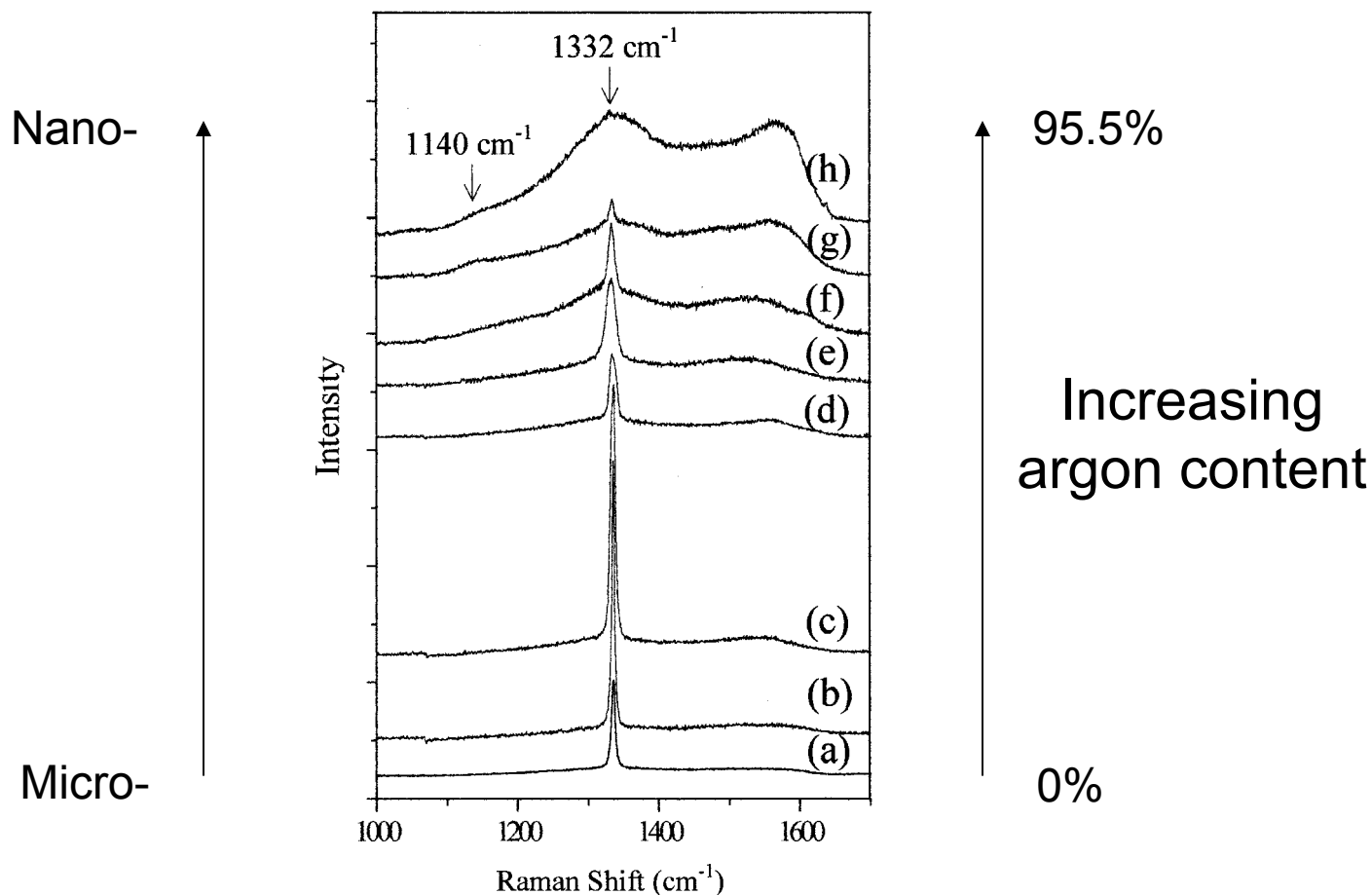
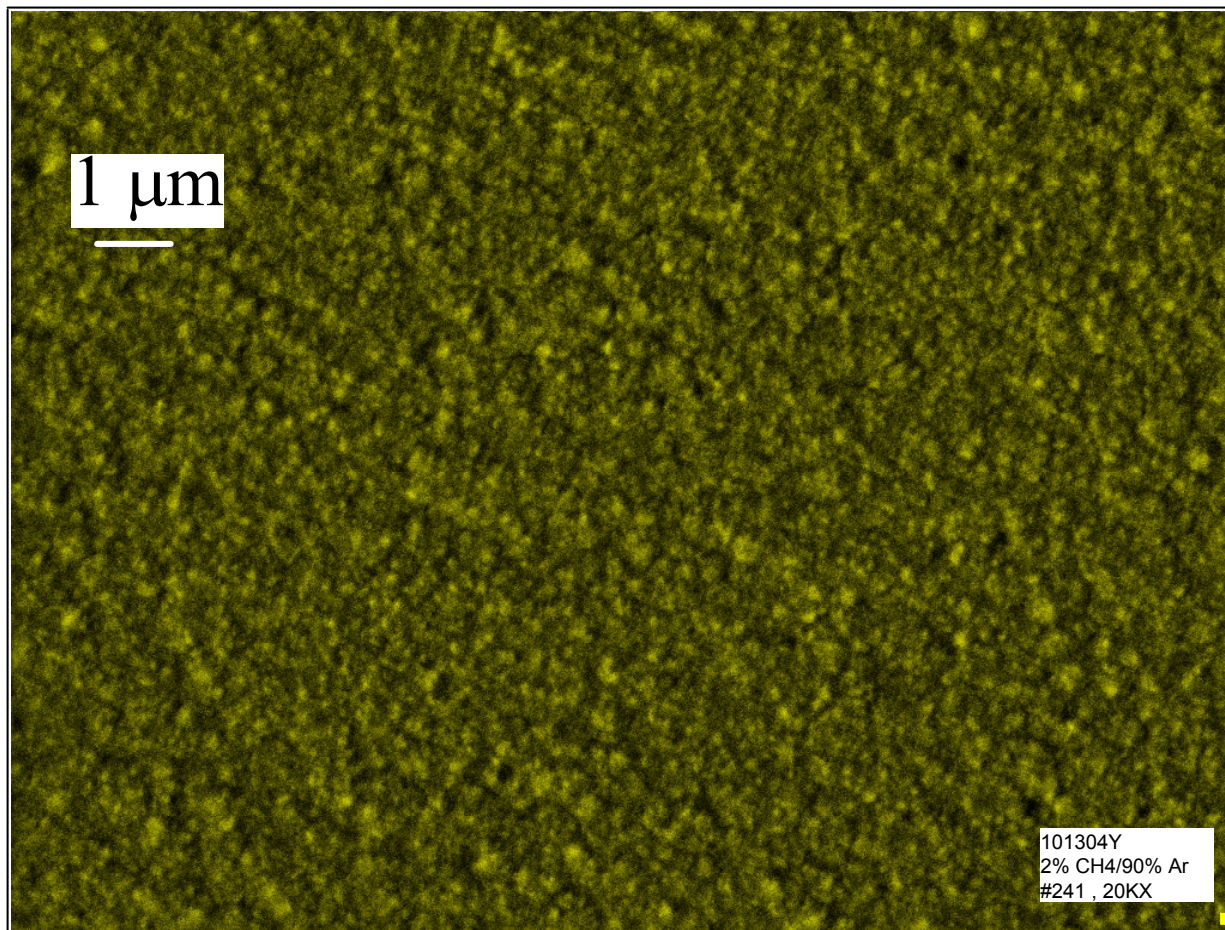
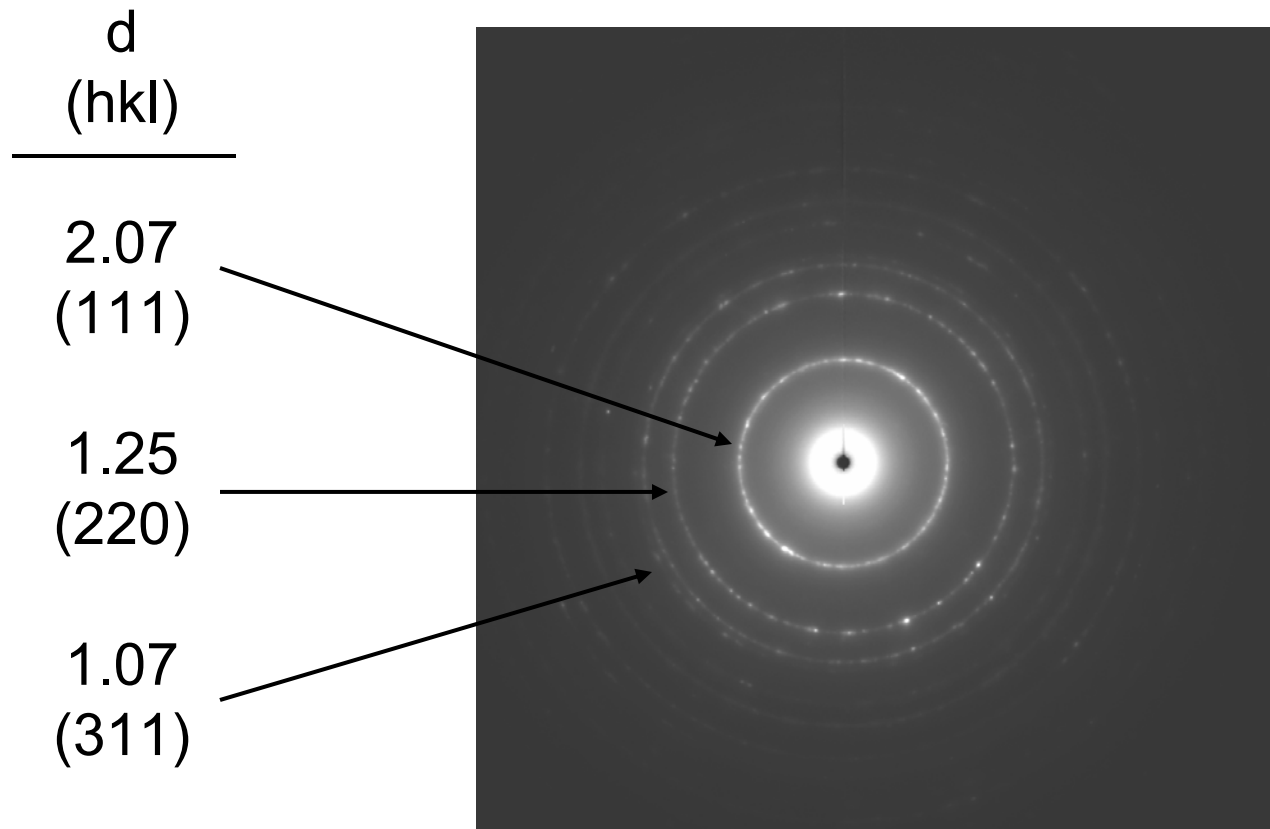


FIG. 4. Micro-Raman spectra of HFCVD diamond grown at increasing Ar volume fraction (a) 0%; (b) 20%; (c) 50%; (d) 80%; (e) 90%; (f) 92%; (g) 94%; and (h) 95.5% for growth mixture using Ar-CH₄-H₂.

SEM of nanocrystalline diamond film

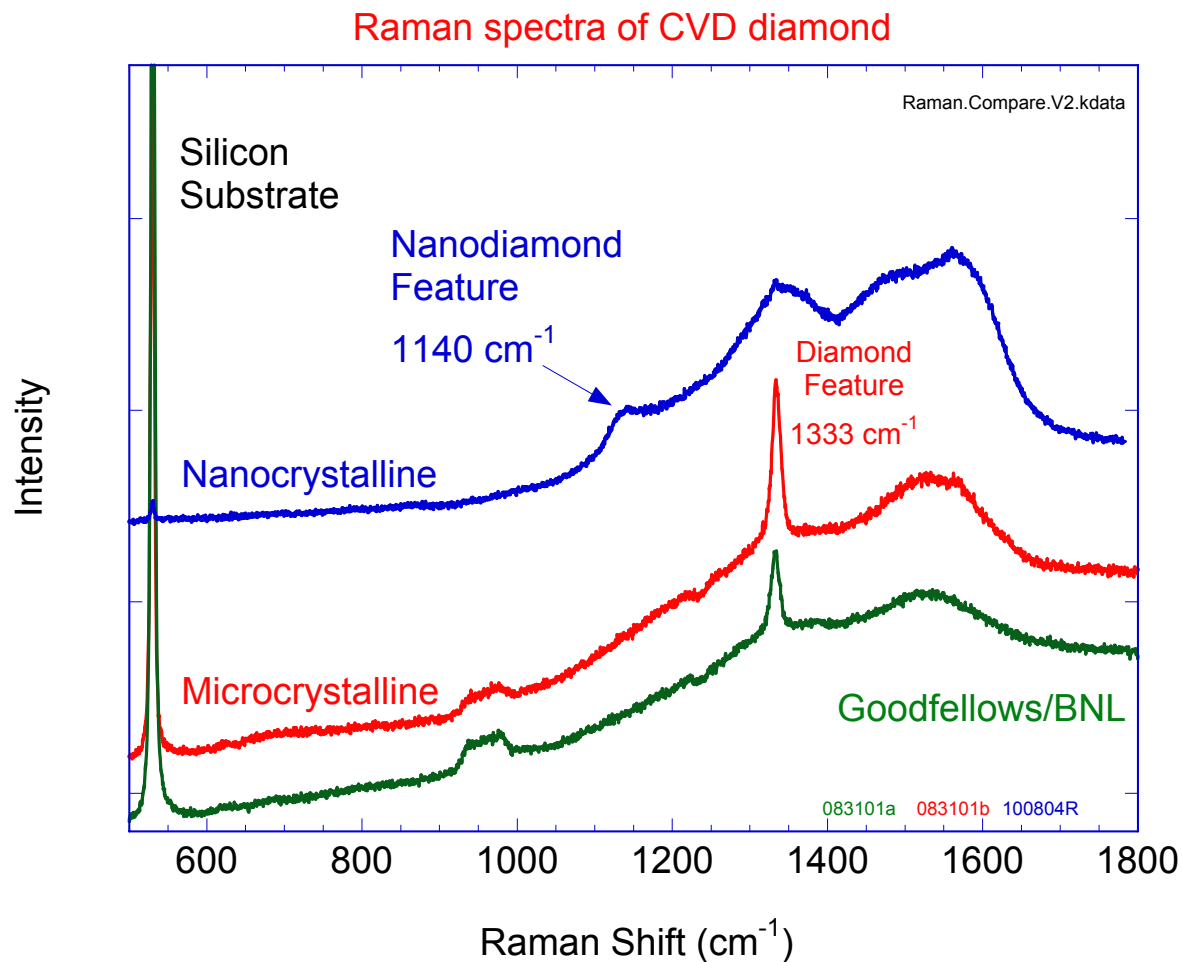


Nano-diamond electron diffraction

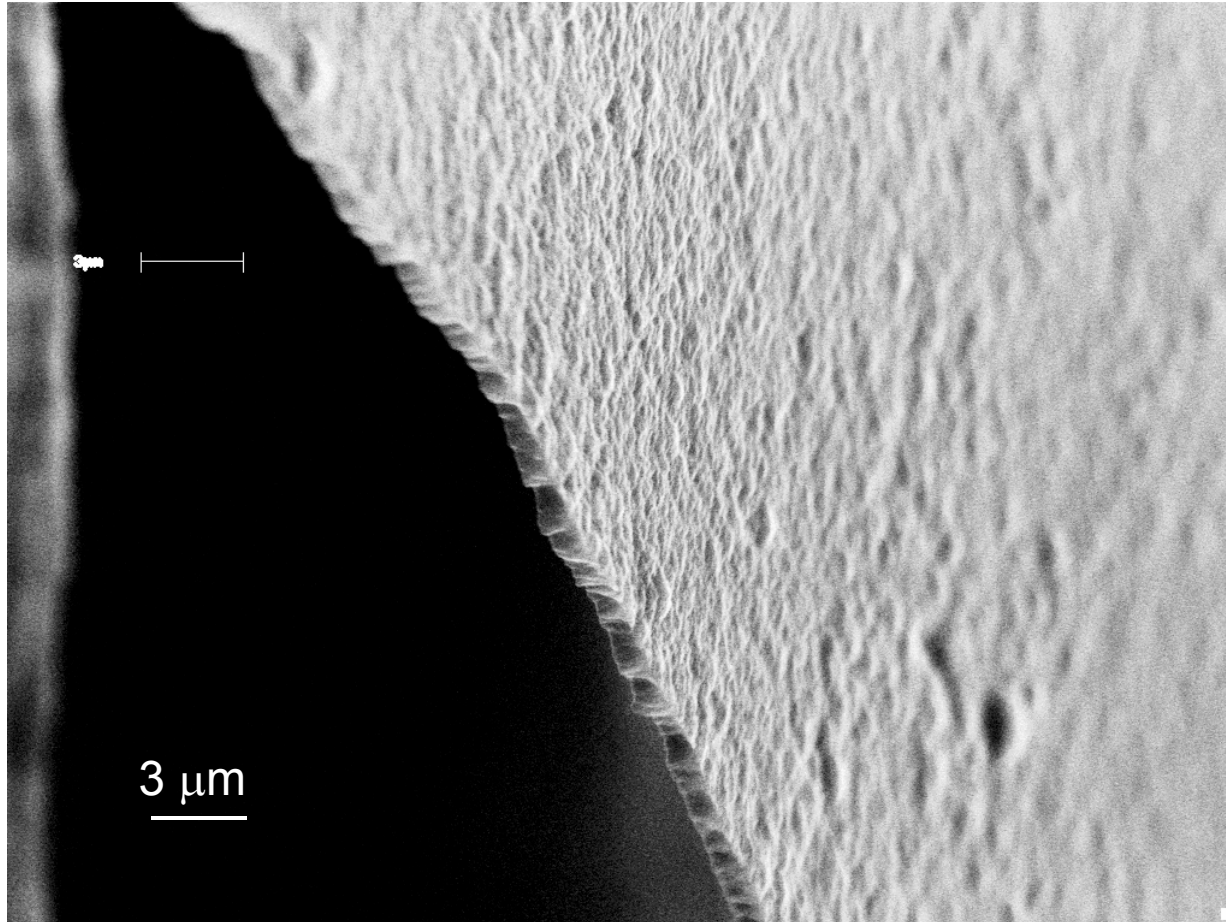


10/04/01
2% CH₄ / 48% H₂ / 50% Ar
ev21756

Diamond Stripping Foils for the SNS



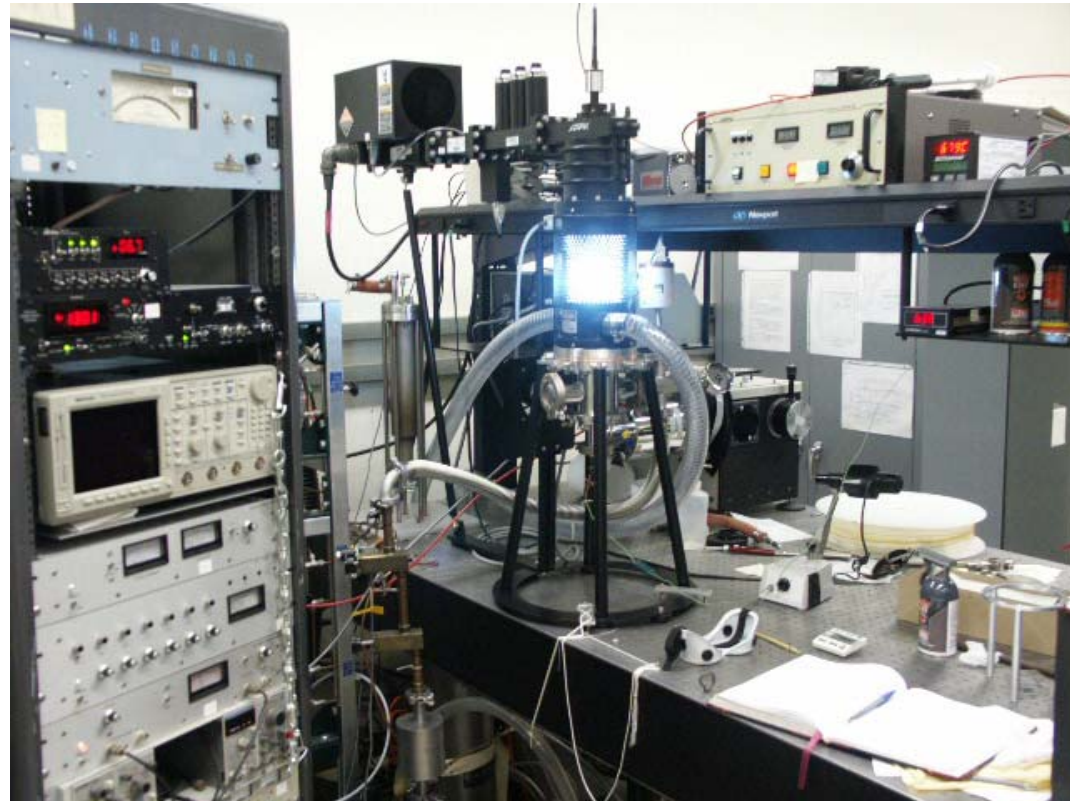
Free standing nano-textured diamond film



10/4/01B from 09/13/01b.Chip2

Microwave-powered growth chamber

- 2.45 GHz
- 1500 Watt
- Uniformity:
up to 1" ϕ



Microwave-powered growth chamber



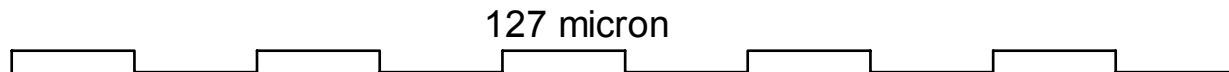
Argon/CH₄ Discharge

Diamond Stripping Foils for the SNS



Corrugated Diamond Pattern

100 Line/In Mask:



Actual:

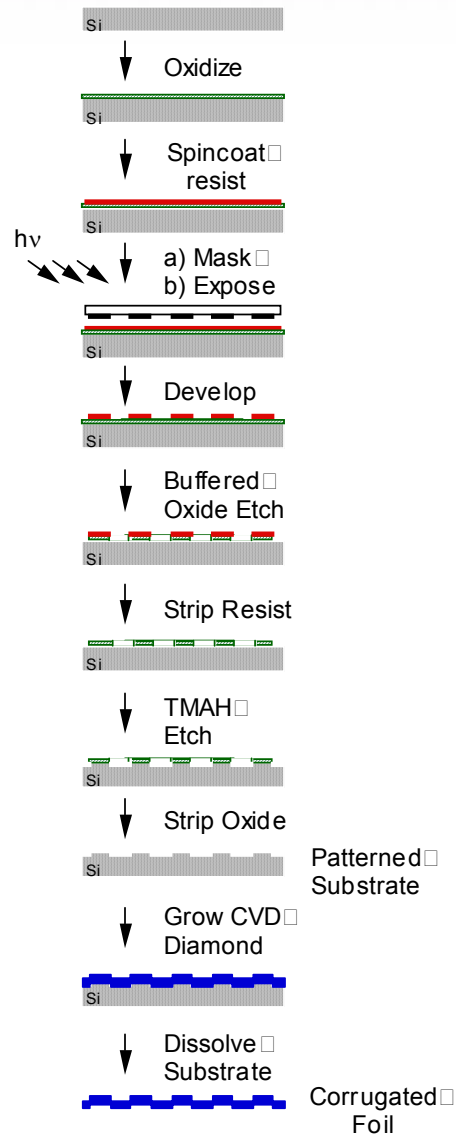


depth = 20 micron

Diamond Stripping Foils for the SNS

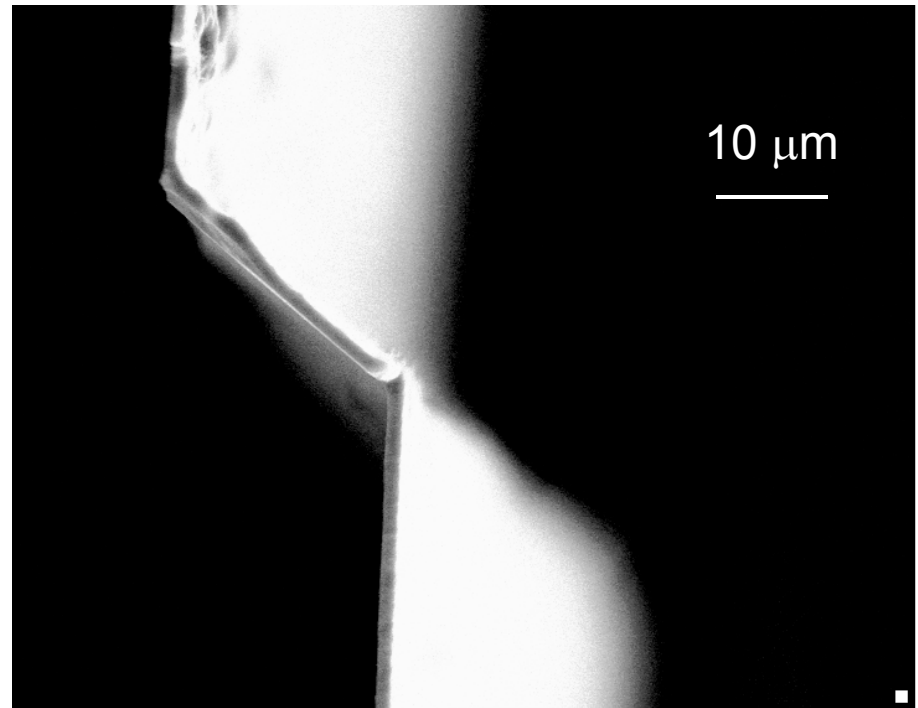
Photolithography □
for Patterned □
Substrates

□ Oxide
■ Resist



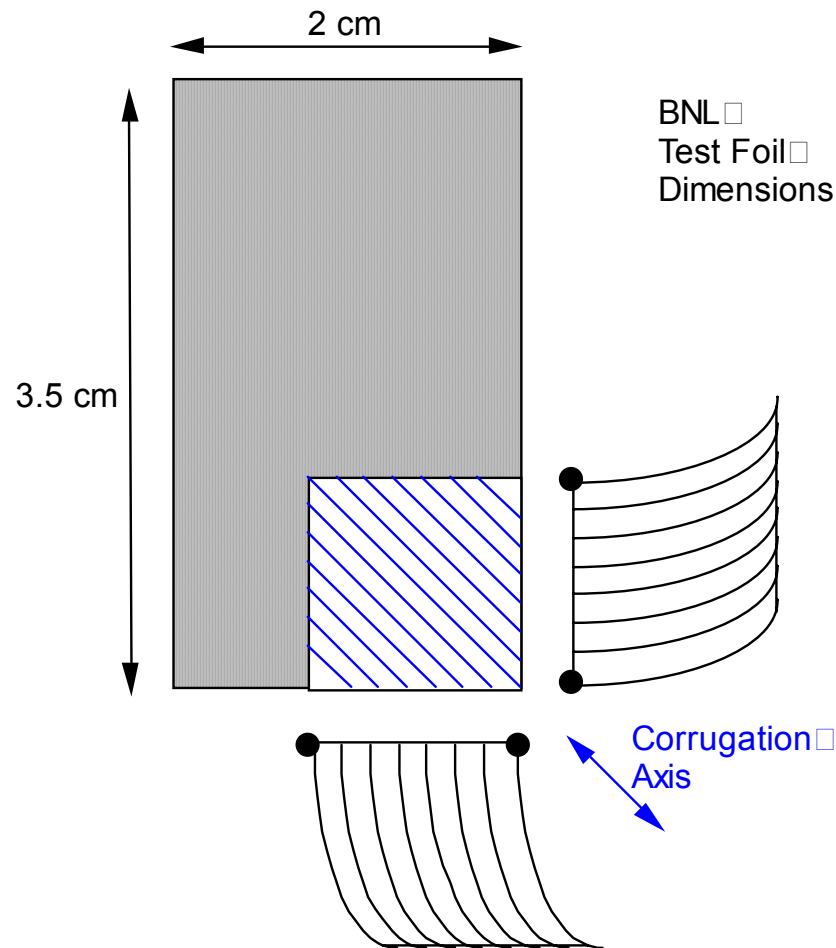
Corrugated CVD diamond foil

- Si <100>
- Pattern at 50 L/in
- Trench depth = 22 μm
- HF grown with argon
 - 2% CH_4 in H_2
 - 50% Ar
 - 40 Torr
 - $T_f = 2300 \text{ K}$
 - $T_{\text{sub}} > 630 \text{ }^\circ\text{C}$
- Acid etch

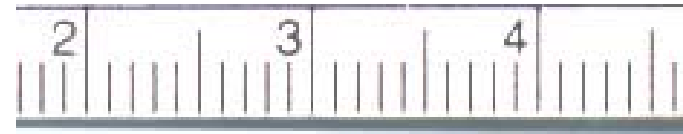


Diamond Stripping Foils for the SNS

Diagonal Corrugation to Pin Film Free Corner



Free standing diamond stripper foil



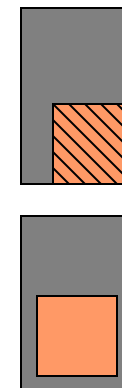
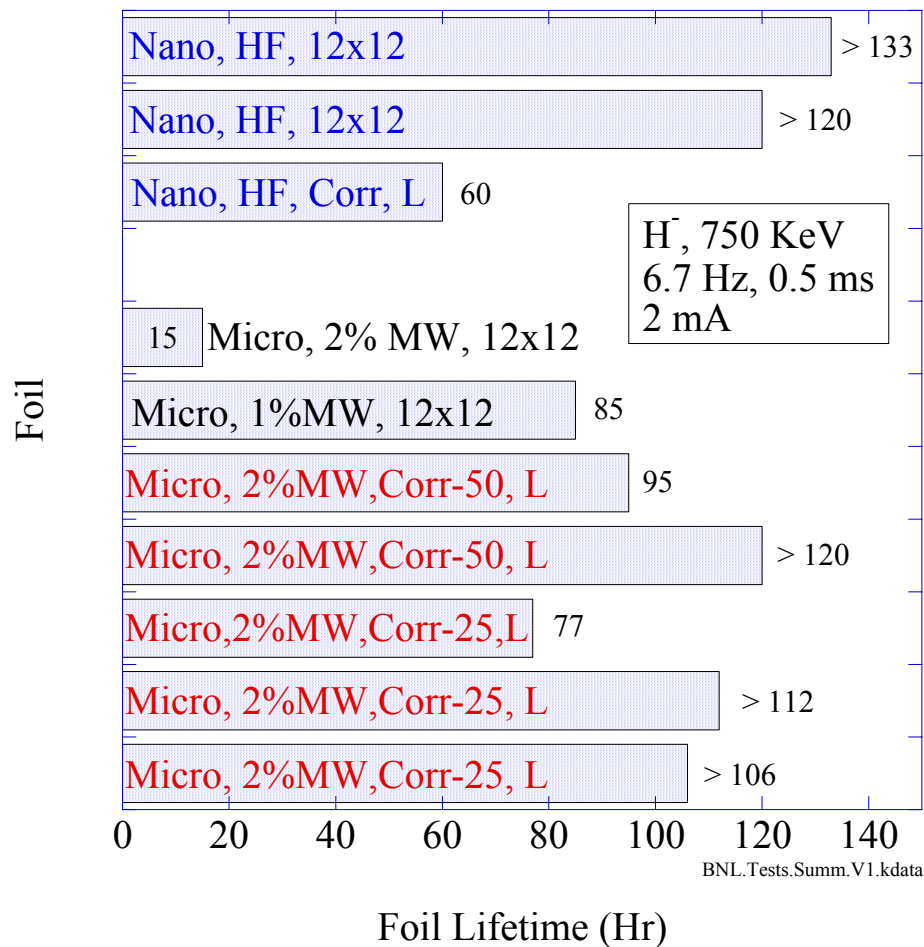
- Patterned Si 50 L/inch
- Scratched/seeded ($0.1\ \mu\text{m}$)
- Hot filament reactor growth
1% CH_4 in H_2
50% Argon
- HNO_3 / HF / CH_3COOH
etch



Diamond foil lifetime tests at Brookhaven 750 keV H⁻ Linac

Diamond Stripping Foils for the SNS

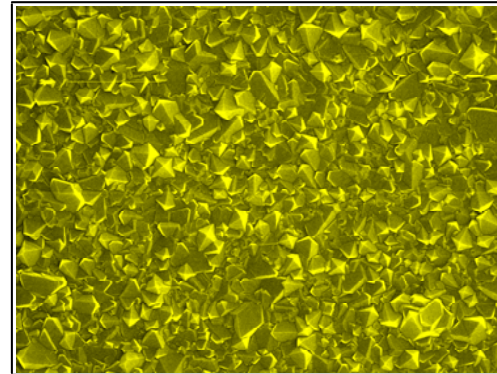
Foil Lifetime Tests at Brookhaven Linac



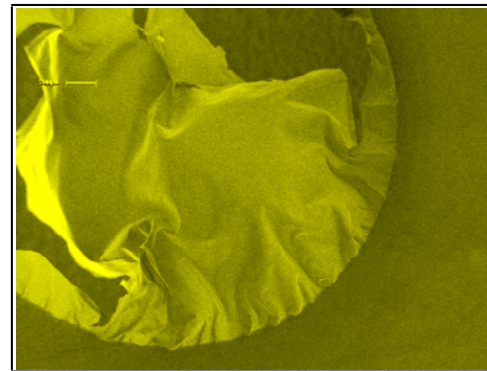
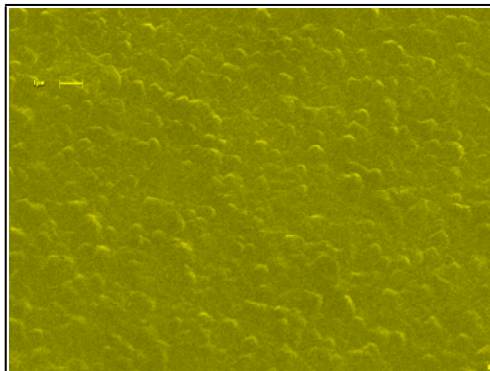
Diamond Stripping Foils for the SNS

*Microcrystalline, microwave-CVD
diamond before and after
BNL H- Beam irradiation*

Before



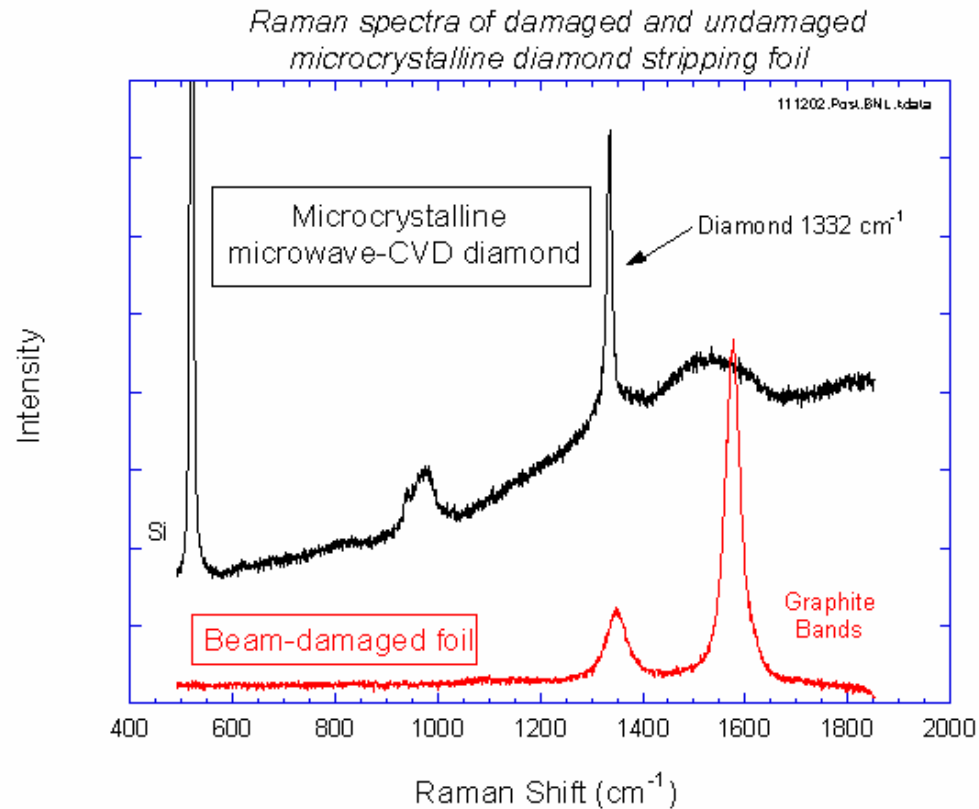
After 16 hours



080602, 2% CH₄, 1300W

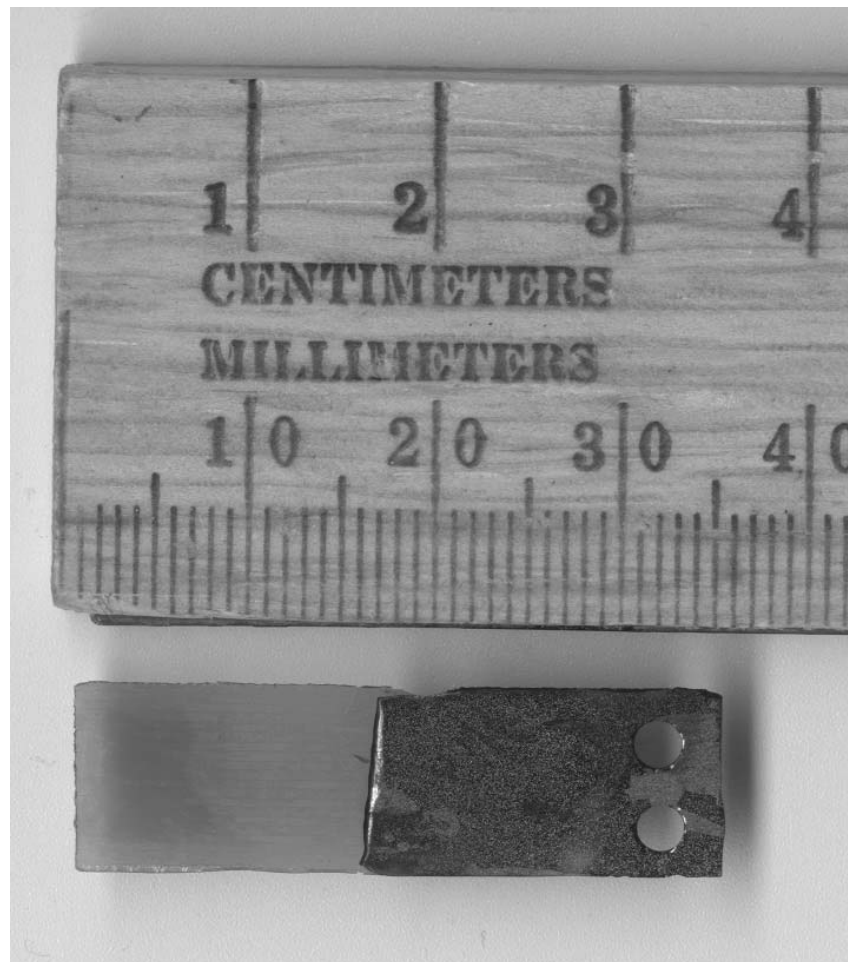
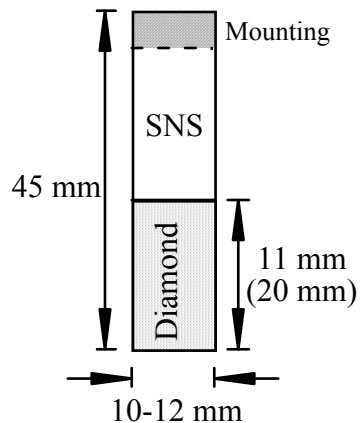
Diamond Stripping Foils for the SNS

Diamond $\xrightarrow{\text{BNL H}^- \text{ Beam}}$ “Graphite” like



Diamond Stripping Foils for the SNS

Single-edge
supported foil
in approx.
SNS format



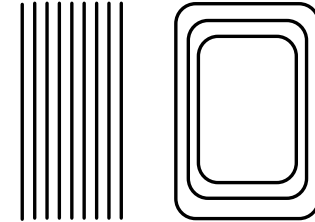
#273
1%,90%
900W
1.7 μ m
25 L/in to
5.2 μ m

Summary

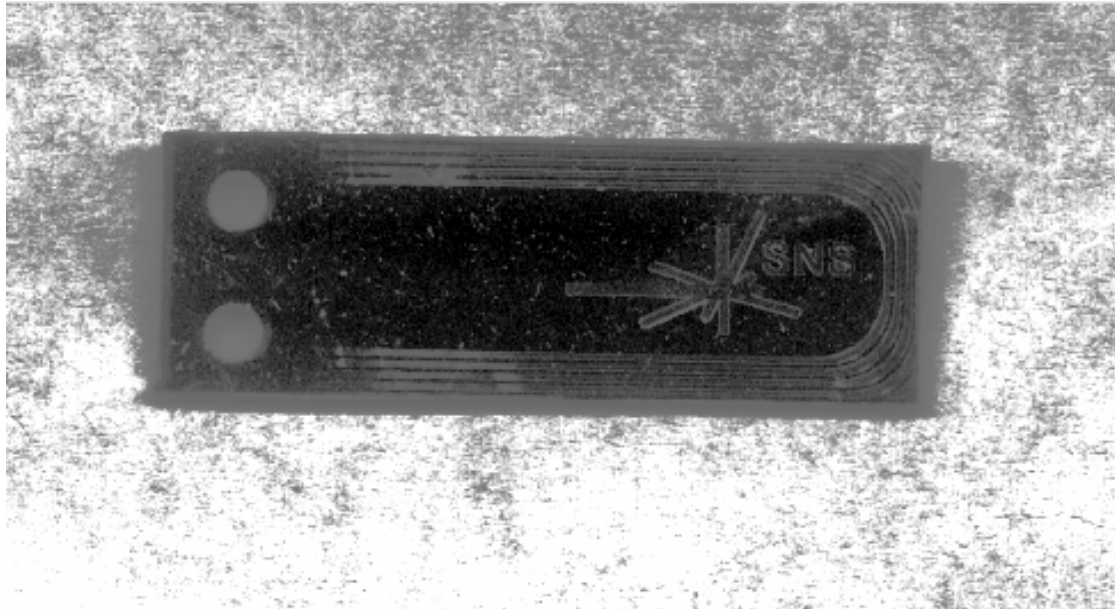
- We have succeeded in preparing continuous films at 1 μm thickness, both micro- and nano-crystalline, at high nucleation density
- Foils have been tested at the BNL H^- beam with lifetimes (to 90% current) as long as 133 hours
 - Nanocrystalline
 - Microcrystalline
 - Corrugated
 - L-Bracket (2-edge support)
- Reproducible life currently at about > 100 hours

Future Efforts

- Single-edge supported diamond foils
 - 2D corrugation patterns
- Lifetime testing for nano- vs micro-crystalline foils
- SNS Linac next to last stage - 186 MeV (Summer 05) ???
PSR tests ???
Fermilab tests ???
- Process handoff and prep lab set-up for SNS

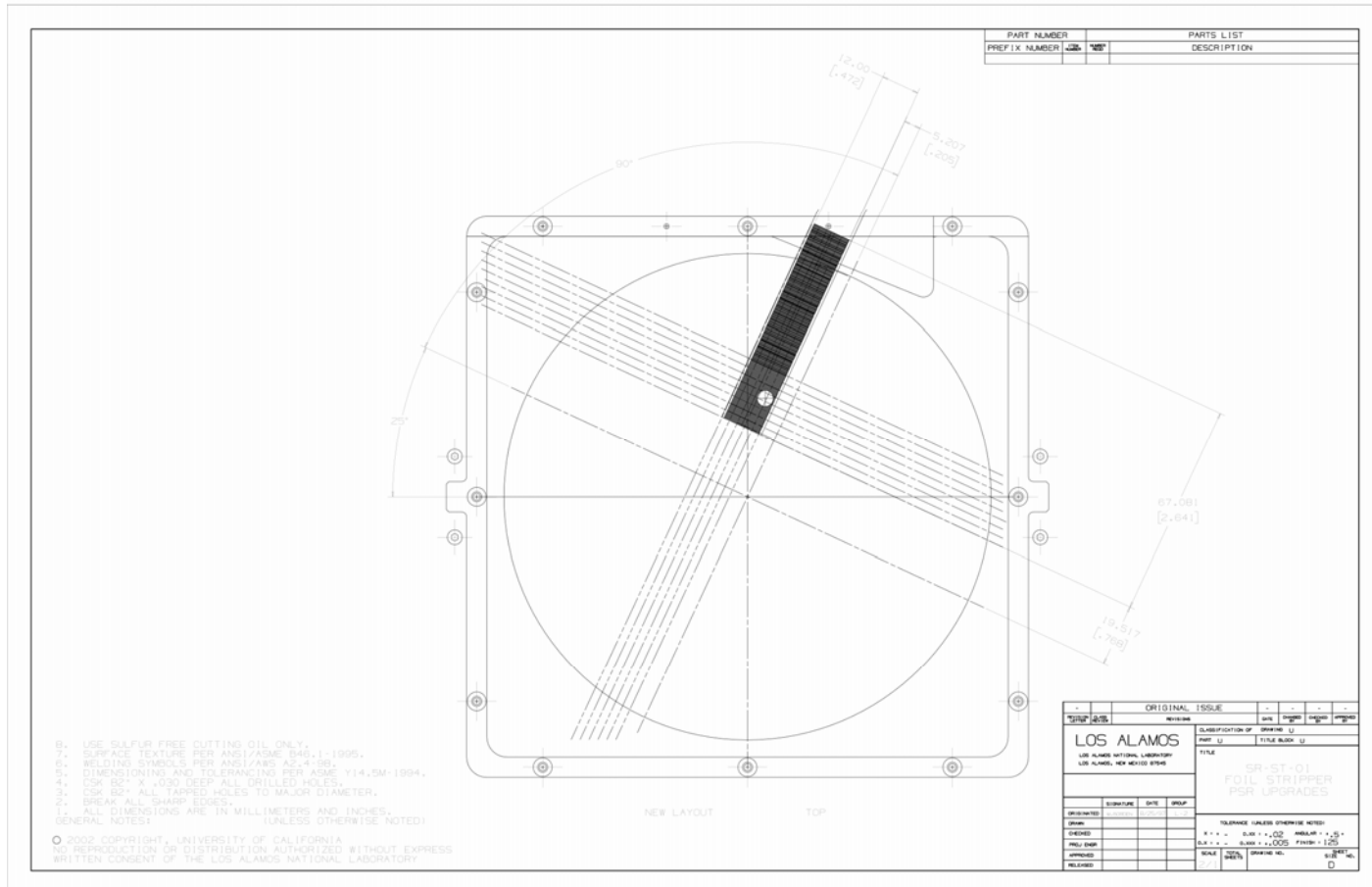


Diamond Stripping Foils for the SNS



Diamond Stripping Foils for the SNS

Possible foil for PSR / LANSCE / LANL test





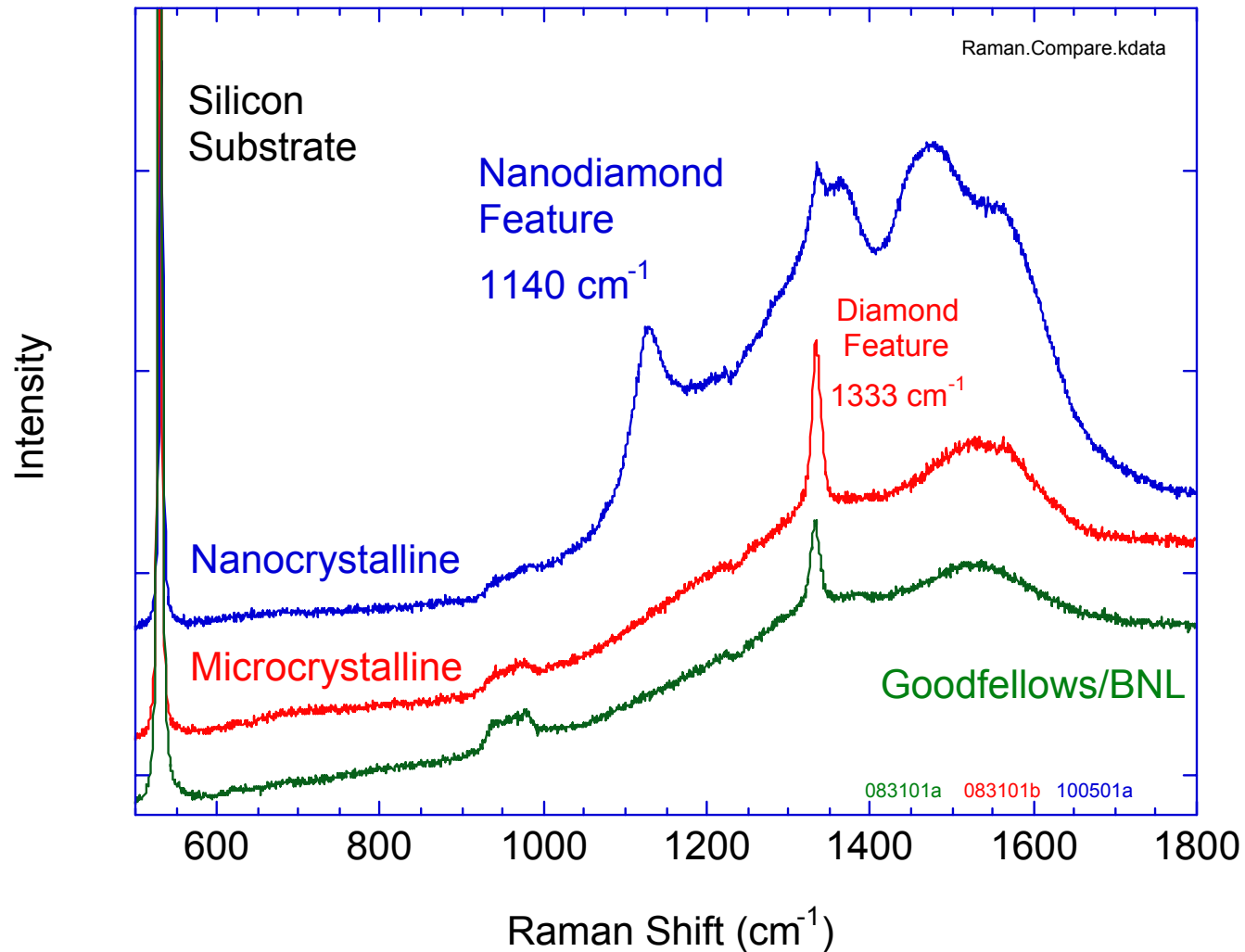
Diamond Stripping Foils for the SNS



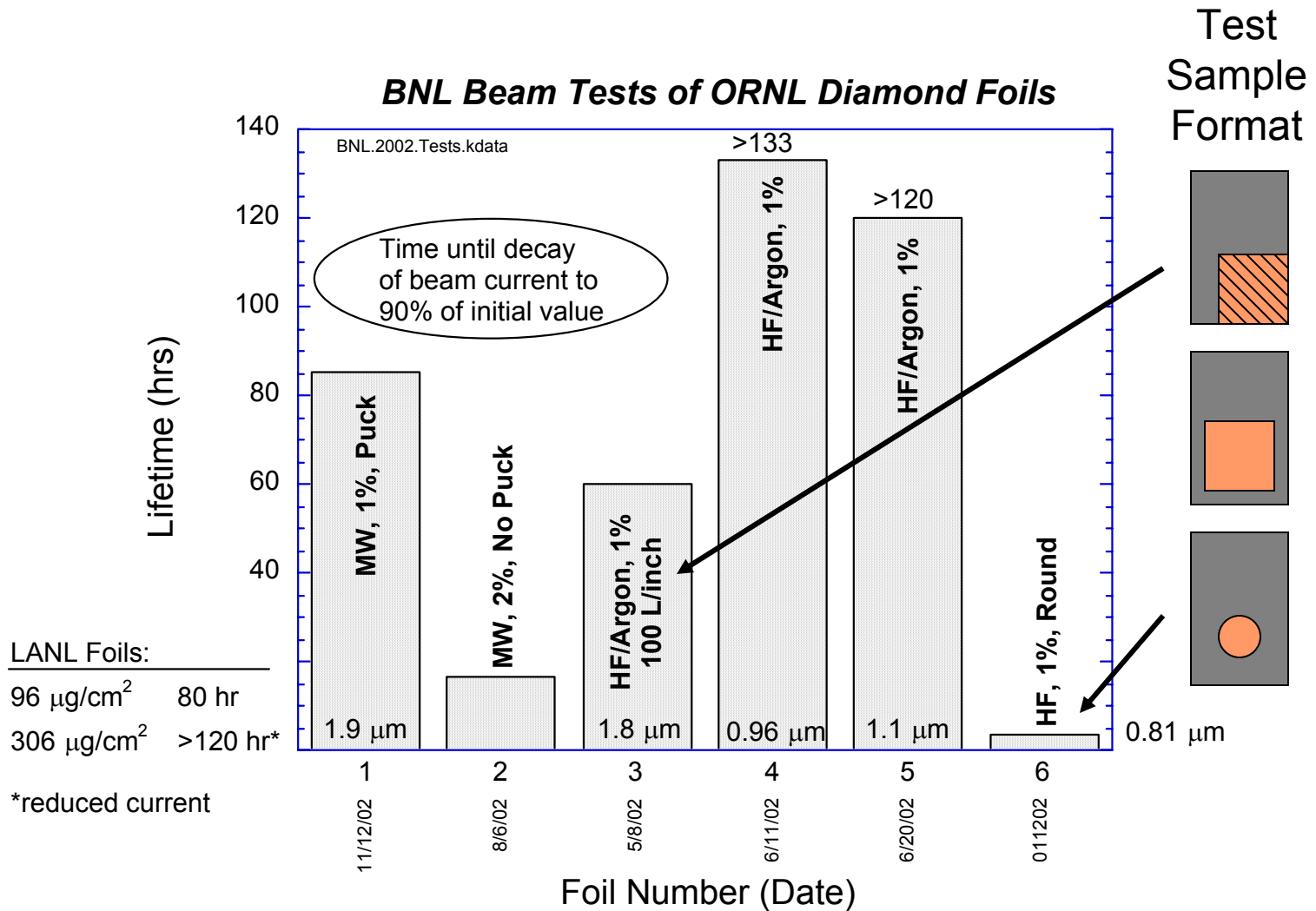
Reference Slides

Diamond Stripping Foil Progress

Raman spectra of CVD diamond



Diamond Stripping Foils for the SNS



Pattern using a 50 line/inch photolithography mask

